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Acoustic Emission Measurement as Adaptive Biomarker in Integrity Analysis of Knee Osteoarthritis

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ABSTRACT
Acoustic emission (AE) technique has been applied as an adaptive biomarker for evaluating the disorder of knee joint. Integrity analysis of knee joint involves a detail study of several anatomical parts of knee joint like bones, cartilage, tendons etc. Any damage of these anatomical parts causes several knee diseases like osteoarthritis (OA). The incidence of knee OA increases due to some damages in the cartilage of knee. The major concern of this disease is the incurability at its matured stage. However, early detection for adopting appropriate measures can reduce the risk of this disease. The present investigation focuses on the dynamical behavioral characterization of knee joint for its integrity analysis with AE parametric features. AE signals have been collected from participants with different ages healthy people as well as OA patients. Data have been collected and clarified according to the guidelines of the ethics committee of Saga University, Japan. **150 words**.

Keywords: Integrity of Knee Joint, Osteoarthritis, Acoustic Emission, Biomarker.

1. Introduction

The knee joint is anatomically made up of three bones and various ligaments. Femur (the thigh bone), tibia (the shin bone), and patella (the kneecap) are the major components of this joint. Knee joint provides necessary supports to the skeleton for allowing them to be flexible in movements. The motion control as well as the protection of the knee joint is done by several muscles and ligaments. These ligaments of the knee ensure that the body-weight must be transmitted through the knee axis for minimizing the amount of wear and tear on the cartilage inside the knee [1].

The knee joint like other joints provides necessary supports to the skeleton for allowing them to be flexible in movements. In this joint, bones are not directly contacted to each other. They are receiving cushiony supports by cartilage, synovial membrane and fluid inside the joint (meniscus fluid). However, due to getting ages, the quality of bones including the cushiony items are degenerated. One of the reasons is that as one ages the meniscus loses water content and the cushiony supports become less rubbery and therefore, the meniscus tears with little efforts. Moreover, muscles and ligaments provide the appropriate forces and strength to this joint for suitable movements. However, the quality as well as the quantity of muscle and synovial tissues are also degraded due to aging and thus, the balancing of knee joint decreased. Therefore, the surface roughness of the articular cartilage is increased and the risk of happening the osteoarthritis (OA) is also increased.

Potential methods like X-ray, magnetic resonance imaging (MRI) etc. are presently using for clinical diagnosis of knee diseases. However, externally inserted high energy to the body for diagnosis of these technique and their static sensitivity with high cost make them unpleasant to the patient. In the contrary, proposed acoustic emission (AE) technique is considered safe and user-friendly diagnosis of knee joint with low cost in dynamic analysis mode [2].

Acoustic emission technique (AET) is an important addition to NDT (non-destructive testing) or NDE (non-destructive evaluation) methods surveying actively a structure by scanning for geometric defects as well as to visual inspection methods observing a material surface. Unlike to other NDT methods, the AET is often used during loading to a structure, not before or after the loading like most of other techniques. Therefore, AET can be successfully applied to characterize the failure of a structure or joint from a very beginning to its complete failure. In AET, acoustic emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stressing a material. When a structure is subjected to an external stimulus (changes in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors. The Parametric analysis of AE signals reveals the damage information of the structure. Having the advantage of non-destructive damage evaluation, recent interests have been focused on the application of AE technique to the biomedical applications. Crack initiation and propagation in human femur is also investigated by a single-sensor technique, however, due to lot of artefacts in sensing systems, continuous efforts in this topic are still due in developing AET as a reliable biomarker [3].

It is mentioned that one of major advantages of AET is its simple application in identification of damage initiation and propagation inside a structure even in minute scales. Furthermore, knee joint gets degeneration due to ages and thus elderly people commonly face

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osteoarthritis disease which loses their workability and makes them a burden to the society. Therefore, the main objective of the present research is to develop a simply applicable biomarker based on AE nondestructive evaluation technique for early evaluation of knee joint degeneration. Accordingly, knees of young, middle aged as well as older people have been investigated by AET in the present research for getting information about initiation of degeneration in knee joint under sit-stand-sit dynamic loading which create sufficient rubbing activities to the surface of cartilage. Furthermore, angular positions of AE events are aimed as well to clarify the distribution of degeneration in all groups. Thus, in the next section, experimental methodology is discussed, after which results and discussion are explained and finally conclusions and references are presented [4].

2. Paper size and Margins

2.1 Experimental set up

The acquisition system of AE signals from knee joint has been designed according to the schematic views as shown in Fig. 1. Four AE sensors (R6α, Physical Acoustics Corporation) with an operating frequency range of 35 to 100 kHz and resonant frequency of 55 is used in the experiment. The sensors are connected to the signal acquisition device (digital oscilloscope) through pre-amplifiers and main AE amplifier and finally the data has been transferred to the personal computer (PC). For the acquisition of angular movements of the knee during sit-stand-sit motions, two channel goniometer has been used for getting angular values for each positon and the data has been recorded into the PC.

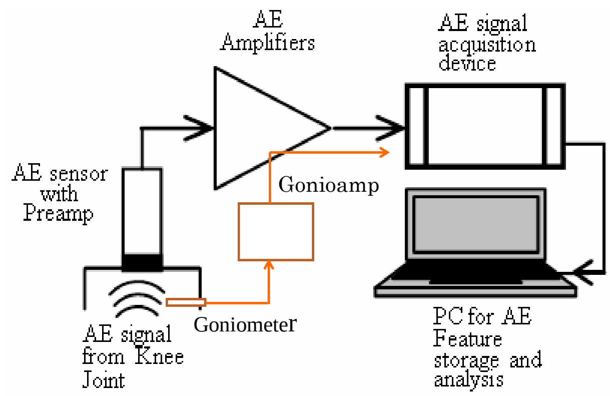

Fig. 1 Schematics of AE signal acquisition set up [ ].

2.2 Experimental procedure

According to the objectives of the present research, the positions of four sensors are placed in four places of the knee so that the generated AE signals can be received from all areas to the sensors. Furthermore, the sensor positions are considered considering as minimum noise receiving positions due to muscles etc. A model knee is shown (3B Scientific GmbH, Germany) in Fig. 2, where the sensor positions are mentioned as well.

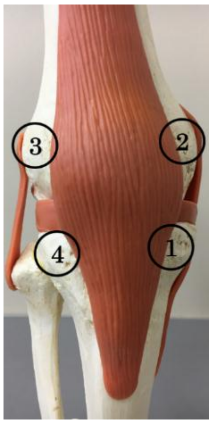

Fig. 2 Sensor positions to knee joint.

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The method of sensor attachment is done by following the rule of ethics as well. As explained above, AE sensors are attached to the positions of (1) to (4) with high elastic medical tape. Due to high elasticity of the tape, the sensors are always attached to the skin of the knee at desired positions during sit-stand-sit movements. Therefore, undesirable noise in the dynamic knee experiments has been avoided remarkably. Moreover, to ensure the continuous contact of the sensing surface of the sensor to the anatomical site of the knee, coupling gel is used between the surface of the sensor and the contact place site of the knee. For getting an angular position of the movements, electronic goniometer is attached to the knee with double-stick tape so that it can be relaxed during the experiment. The position of the goniometer has been initialized to 90 degrees at the sitting position, while at the standing position it has been set to 0 degree. Thus, in one set of movement (sit-stand-sit) the measured angle has been recorded as 180 degrees. Ten sets of movements have been considered as 1 cycle of movements while 1 minutes have been taken as intermittent rest time. However, each cycle has been completed upon receiving one data. Thus, for one participants 30 AE events have been taken. Two participants from each group have been participated in the experiment. For AE signals 1MHz and for goniometer 100 Hz are used as sampling frequencies.

3. Experimental results and discussion

Experimental results for the integrity analysis of knee joint have been summarized as follows. Major focus has been concentrated to the effects of aging on having degeneration in anatomical components of knee joint. It is considered young participants of ages less than 40 and above of 40 it is defined as middle aged or old aged participants. Some results of knee patients are also compared as well, however, that results are not shown in this paper. It is also compared the sensitivity of AE acquisition for sensor positions. It is found that less muscle area for sensor position is better than the other muscle enriched areas. However, collection of AE data for analyzing the integrity of knee joint are shown satisfactory at other places as well. The result is shown in Fig. 3.

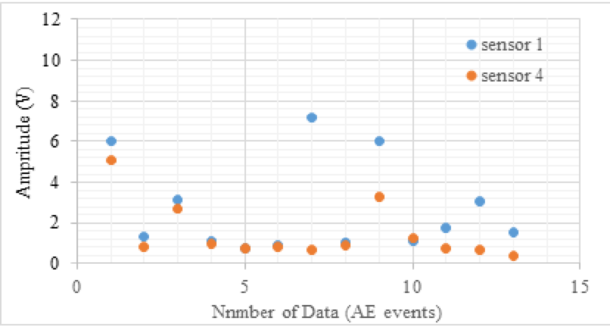

Fig. 3 Sensitivity analysis of sensor positions.

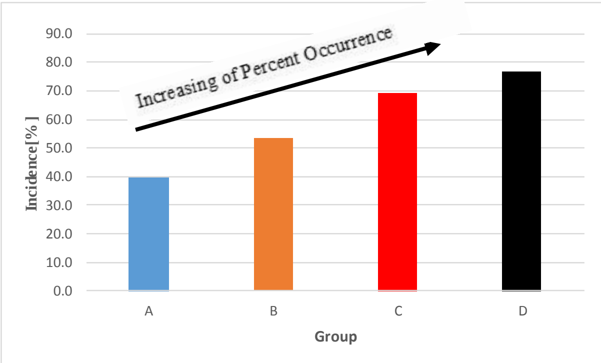

Fig. 4 Percent occurrence distribution of AE hits for different aged participants and OA patients.

The percent occurrence of AE hits is defined as the percent of the ratio of total required sit-stand-sit movements for a fixed number of AE hits in one cycle. As explained in above that the rate of transient AE hit generation increases due to surface condition of knee cartilage decreases. Experimental results show that increasing of aging increasing the percent occurrence of AE hits and it increases more for OA patients (Fig. 4). Thus, according to the observation, percent occurrence of AE hit works as an acceptable bio-marker for knee integrity analysis.

The parametric analysis of AE signals received from the knee joints of young and aged people has been conducted for understanding the signal intensity level and concentration of occurrence [5]. In the present paper, the analysis has been focused to the calculation of maximum amplitude of each AE events. Results of these maximum amplitude analysis for AE signals for two participants are mentioned in Fig. 5. Since the signal amplitude represents the functional proportion of AE signal energy, the result shown in this figure thus focuses on the AE event intensity for young and aged people. Therefore, according to the result, it is found that the AE intensity received from the cartilage friction of knee joint of aged participants is remarkably high compared to the young participants. It is already mentioned that this result has been observed between two groups of participants whose age difference is below 20 years. Therefore, it is thought that similar results can be repeated for similar comparisons among people of young and more elderly group due to having more chance of occurring more degenerations in articular cartilage of knee joint for aging effects.

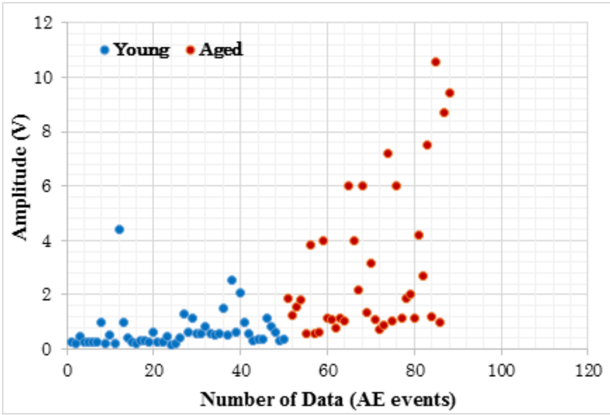

Fig. 5 Amplitude distribution of AE events for young and aged people.

EMG signals from lower limb muscles have been collected for each natural movement of knee joint [6]. The sensor clustering domain has been arranged only for left leg in the present paper. EMG signals are collected for knee flexor and knee extensor activities from the standing and sitting movements of the participants. Each sensor channel has been utilized for collecting individual muscle potentials from the respective muscle during flexor and extensor motions of the knee. One cycle of data collection has been defined as one standing and one sitting (sit-stand-sit) movements. Thus, for each position of the sensor, 20 cycles of data acquisition consist one data set. All of these data have been collected and recorded in PC for further processing.

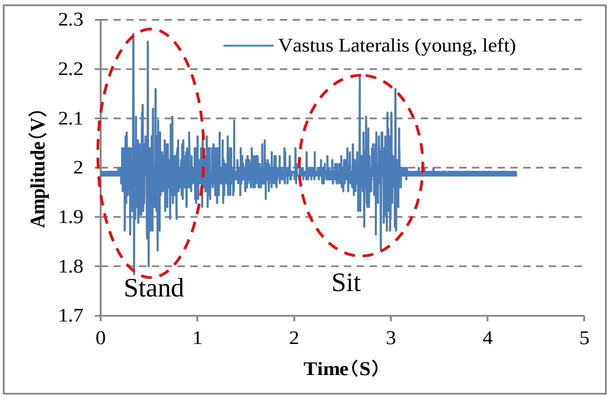

Fig. 6 EMG instantaneous signals for young people, vastus lateralis signals of left leg

The instantaneous EMG signals for young and aged people have been presented in Figs 6 and 7. Signals for vastus lateralis muscles only are found in these figures.

The myoelectric potentials for standing and siting conditions for all muscles are visualized as signal amplitudes in volts. Although, the amplitudes are varied based on the values of the signal potentials at each data cycle, however, the patterns of the muscle potentials are understood from these sampling data. Maximum amplitudes in volts for 20 iterations are summarized individually in standing and sitting cycles for both aged people and young people

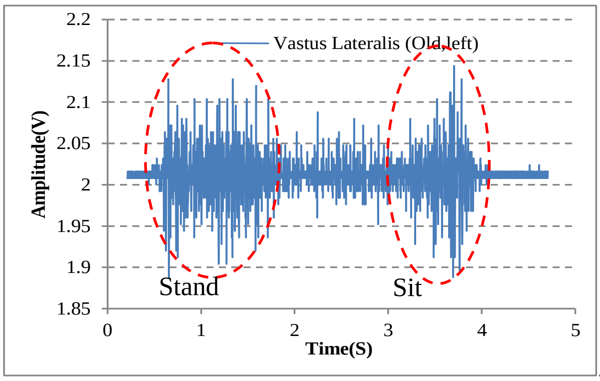

Fig. 7 Instantaneous signals for aged people, vastus lateralis, left leg.

The performance of muscular potential for vastus lateralis muscle has been analyzed as shown in Figs. 8 and 9 as well with respect to its peak frequency (PF) analysis, where, the peak frequency is defined as the frequency regarding to the peak amplitude (maximum amplitude) of each signal. In these figures PF distributions of vastus lateralis muscle for sitting movements are shown only in this paper. Muscle activities are compared according to the performance in sitting movements for both young and older people and found the differences in their activities as well. It is considered as one of the major issues in cartilage damage in older people. Thus, PF distribution analysis for young and old participants have been summarized in this paper considering only the vastus lateralis muscle. However, similar results are shown in other muscles for standing dynamics mode of older and younger people respectively. Strong PF perturbations are found as well in EMG signals for sitting operation of older people compared to that of younger people.

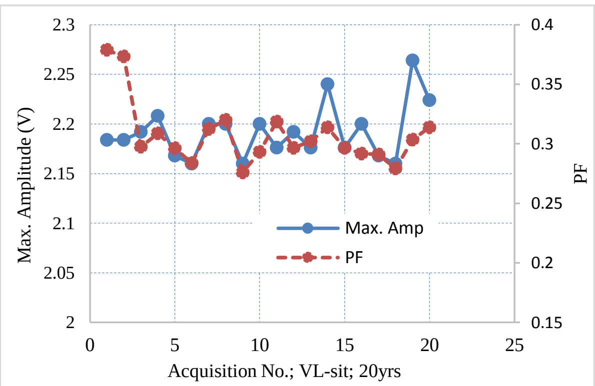

Fig. 8 Amplitude vs. PF of young people, vastus lateralis for sitting.

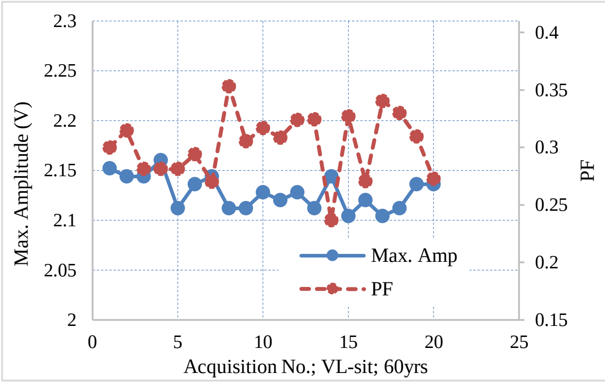

Fig. 9 Amplitude vs. PF of aged people, vastus lateralis for sitting.

4. Conclusions

Acoustic Emission technique has been applied in the integrity analysis of knee joint. Several bio-markers for knee osteoarthritis (OA) diagnosis based on AE technique have been explained with experimental validations. According to the objectives, two major findings have been clarified by the proposed system. Degeneration of knee cartilage by aging have been successfully identified by the proposed AE technique. Furthermore, integrity analysis of damaged knee by OA is also clarified satisfactorily. Maximum amplitude distribution of AE hits, percent occurrence of AE hits and concentrated distribution of AE hits etc. are presented as successful bio-markers in the AE diagnosis system of knee problems including OA. Muscles activities related to knee activities are also clarified by applying EMG signal processing technique. It is observed that the reduction of muscle activities due to aging may play an active role in causing degeneration of cartilage for occurring OA in knee joints.

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